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# Advances In The Soluble Tablet Formulation Of Metarhizium Anisopliae As A Mycoinsecticide: A Systematic Review Of Biotechnological Innovations In Biological Control Of Insects

**Trinh Thi Xuan [1*], Pham Kim Son[2] and Le Thi Ngoc Xuan[3]**

Plant Protection Department, College of Agriculture, Can Tho University; Can Tho city, Vietnam
[1]trinhthixuan@ctu.edu.vn, [2]ltnxuan@ctu.edu.vn and [3]pkson@ctu.edu.vn
[1]https://orcid.org/0009-0002-0513-7922, [2]https://orcid.org/0009-0004-6940-3921 and
[3]https://orcid.org/0009-0004-9194-5719

## ABSTRACT

*The systematic literature review investigates the advancements in Metarhizium anisopliae's (M. anisopliae) soluble tablet formulations for enhanced biocontrol applications. This review consolidates research from 2022 to 2025, focusing on improving the stability, efficacy, and field performance of M. anisopliae formulations. A systematic review followed PRISMA guidelines, with articles retrieved from PubMed, Web of Science, Scopus, and Google Scholar databases using Boolean operators. Inclusion criteria were applied to studies that specifically addressed M. anisopliae soluble tablet formulations, evaluating their stability, application efficiency, and field performance. The Newcastle-Ottawa Scale (NOS) was utilized to assess the quality of studies and minimize potential biases. The review reveals that soluble tablet formulations significantly enhance conidial stability, ensure prolonged viability under extreme environmental conditions, and improve application efficiency. Key advancements include using biopolymer matrices, such as chitosan and alginate, which provide protective coatings that extend the shelf life and ensure controlled spore release. Additionally, formulations incorporating oil-in-glycerol systems have successfully improved thermal stability, preventing conidial degradation at high temperatures. However, challenges in large-scale production and cost optimization remain, which hinder widespread adoption. The review emphasizes the need for further research into improving production techniques and standardizing formulations for greater commercial feasibility. This study supports the integration of M. anisopliae soluble tablets into Integrated Pest Management (IPM) systems as a promising alternative to traditional biopesticides, addressing issues related to shelf life, ease of use, and environmental adaptability. Future research should focus on optimizing large-scale production, evaluating long-term field performance, and exploring cost-effective production methods to ensure sustainability in agricultural pest control.*

**Keywords:** *Metarhizium anisopliae, Soluble tablet formulation, Biopesticide stability, Integrated Pest Management (IPM), Entomopathogenic fungi, Biopolymer matrices, Conidial viability, Pest control sustainability, Thermal stability.*

## 1. INTRODUCTION

Biological control is one of the fundamental principles of IPM that involves protecting and encouraging the use of natural enemies of pests. This does not harm the environment compared to the chemical insecticides polluting water sources and the soil. In addition, they are toxic to other insects and animals. Chemical insecticides have adverse effects, including pest resistance and environmental impact; therefore, biological control methods are needed (Sharma & Sharma, 2021; Sutthisa et al., 2024). Metarhizium anisopliae (M. anisopliae) is an entomopathogenic fungus that can infect several insects. It targets the exoskeleton of the insect, causing its death through mycosis. For instance, Lei et al. (2022) found that such formulations improved the conidial stability and shelf life, which improved the field performance against pests like red palm weevil (Rhynchophorus ferrugineus).

Traditional formulations of biocontrol agents, including M. anisopliae, have been previously developed, including liquid suspension and wettable powder. However, these formulations have several drawbacks, including shorter shelf-life, lower stability under environmental conditions, and difficulties in formulation.

For example, conidial viability can be affected by high temperatures, and factors such as these impede the effectiveness of these formulations (Baker et al., 2020; Hu & St Leger, 2002; Sönmez et al., 2022). As a response, soluble tablet formulations have emerged as a novel delivery method designed to enhance conidial stability, prolong shelf life, and improve application convenience. This approach ensures controlled spore release and protects fungal conidia from environmental degradation while increasing field efficiency. The present study critically reviews advancements in the formulation of M. anisopliae in soluble tablets, evaluating their potential as effective and scalable mycoinsecticides. The review focuses on innovations in formulation techniques, including biopolymer matrices, genetic modifications for heat tolerance, and storage improvements, while addressing challenges such as production scalability and cost-effectiveness.

## 2. METHODS

### 2.1 Research Design and Approach

The review employs a systematic approach following PRISMA 2020 standards to analyses M. anisopliae soluble tablet formulation as mycoinsecticide. The PRISMA 2020 statement provides reporting standards by identifying, selecting, evaluating, and synthesizing relevant studies (Moher et al., 2009).

### 2.2 Data Sources and Search Strategy

Databases, including PubMed, Web of Science, Scopus, and Google Scholar, were used to identify studies published between 2021 and 2025. Combining specific keywords and Boolean operators was also used to identify relevant articles. The search strings included:

("Metarhizium anisopliae" AND "soluble tablet" AND "mycoinsecticide") OR ("Metarhizium anisopliae" AND "biopesticide formulation" AND "shelf life") OR ("Metarhizium anisopliae" AND "microbial insecticide" AND "conidial viability") OR ("entomopathogenic fungi" AND "soluble tablet" AND "sustainable pest control") OR ("fungal biocontrol" AND "tablet formulation" AND "field application")

Additional terms such as "formulation," "biopesticide," and "field efficacy" were also incorporated to broaden the search. The search was limited to studies published in English and excluded non-peer-reviewed sources to ensure the inclusion of high-quality evidence.

### 2.3 Inclusion and Exclusion Criteria

**Inclusion Criteria:**

- Studies published between 2021-2025 focusing on developing and evaluating M. anisopliae in soluble tablet formulations.
- Research addressing innovations in mycoinsecticide formulations, including novel delivery systems and application methods.
- Articles reporting on these formulations' stability, efficacy, and field performance.

**Exclusion Criteria:**

- Non-peer-reviewed articles, conference abstracts, and grey literature lacking rigorous scientific evaluation.
- Studies on outdated formulations of M. anisopliae are irrelevant to current biotechnological advancements.
- Research focusing on non-relevant fungal biopesticides or those not utilizing soluble tablet formulations.
- Studies published before 2021, unless they provide foundational insights directly relevant to current advancements.

### 2.4 Data Extraction and Synthesis

The data was gathered by two researchers focusing on the changes in formulation, viability of the fungi, application efficiency, and field performance. The changes in the formulation concerning carriers, stabilizers, and surfactants were then evaluated. The viability of the fungi was determined from the number of conidia that germinated following the incubation periods under various conditions. Dosage spread ability and adhesion were assessed regarding application efficiency, while pest mortality and change in crop yield were determined as field performance. A qualitative synthesis categorisation of the results about formulation type, application method, and efficacy was performed to understand the current prospects and limitations of M. anisopliae soluble tablets.

### 2.5 Quality Assessment

Newcastle-Ottawa Scale (NOS) was applied to assess the quality of all the articles included in the current systematic review (Table 1). This tool was used to evaluate studies based on selection (study population and exposure measurement), comparability (control for confounding factors), and outcome (assessment methods and follow-up adequacy), with a maximum score of nine stars. Only studies meeting a minimum quality threshold were included in the final analysis, ensuring reliable and reproducible findings on M. anisopliae soluble tablet formulations.

**Table 1** Quality Assessment of Studies

| Study | Selection Representativeness | Selection Exposed Cohort | Ascertainment | Comparability Results Not Present at the Start of the Study | Comparability for Confounders | Outcome | Outcome Assessment | Follow-up Duration | Adequacy of Follow-up | Total Score |
|---|---|---|---|---|---|---|---|---|---|---|
| Lei et al., 2021 | * | * | * | * | * | * | * | * | * | 9 |
| Wasuwan et al., 2022 | * | * | * | * | * | * | * | * | * | 9 |
| Almeida et al., 2023 | * | * | * | * | * | * | * | * | * | 9 |
| Sutthisa et al., 2024 | * | * | * | * | * | * | * | * | * | 9 |
| Villamizar et al., 2021 | * | * | * | * | * | * | * | * | * | 9 |
| Ranadev et al., 2024 | * | * | * | * | * | * | * | * | * | 9 |
| Gómez-Valderrama et al., 2022 | * | * | * | * | * | * | * | * | * | 9 |
| Trinh et al., 2024 | * | * | * | * | * | * | * | * | * | 9 |

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## 3. RESULTS

The process involved a database search of 1000 records. After removing 500 duplicates, 500 records were used for screening. The automated tools excluded none, and no additional cases could have been excluded. Of these, 420 were removed based on their titles and abstracts. The remaining 80 full-text articles were further assessed for eligibility. Upon full-text evaluation, 76 studies were excluded due to missing critical data. This left 7 final studies that met all inclusion criteria and were selected for in-depth review and thematic analysis. Adhering to the PRISMA 2020 guidelines, this process ensured that the review was systematic and transparent.

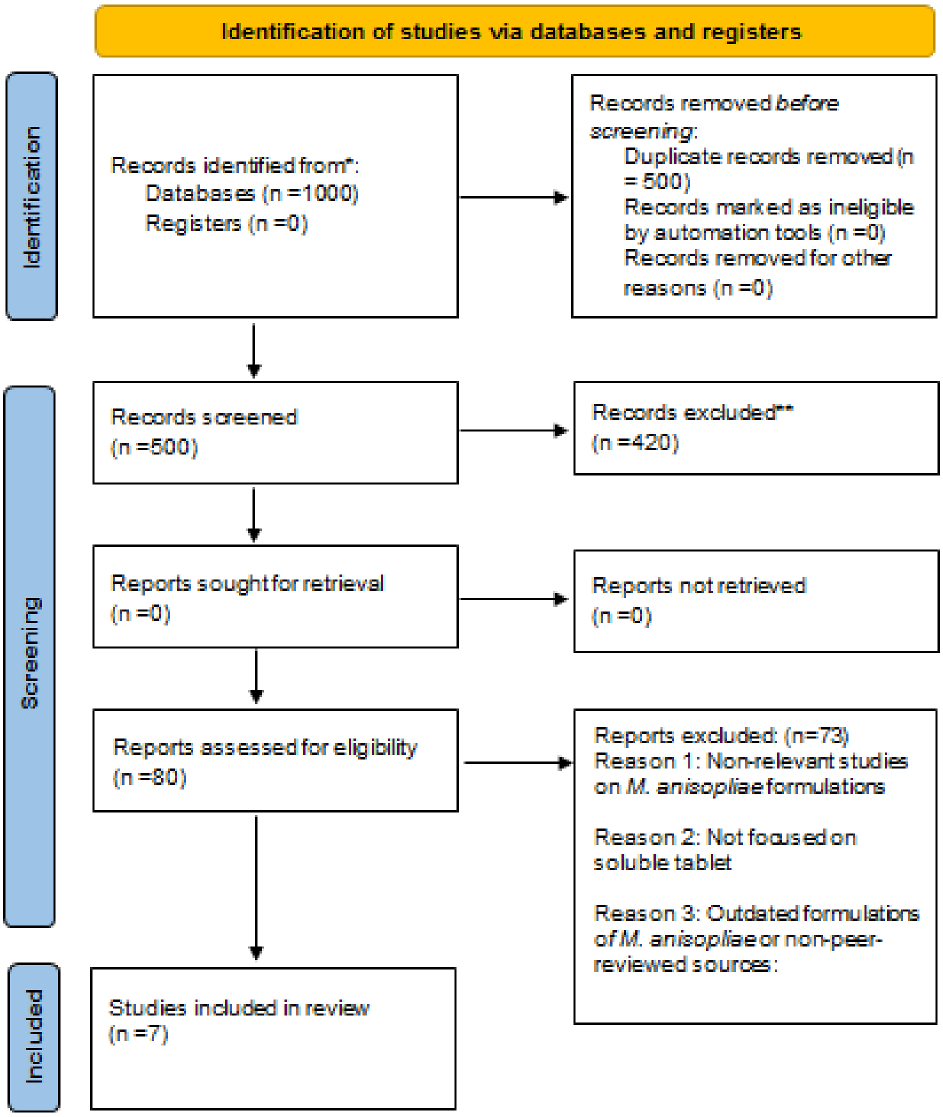


**Figure 1** PRISMA Framework

**Table 1** Study Table

| Authors & Year | Objective | Methodology | Key Findings | Formulation Type | Viability Duration | Pest Target | Mortality Rate | Storage Conditions | Substrate/ Excipient Used |
|---|---|---|---|---|---|---|---|---|---|
| Lei et al., 2021 | To develop an oil-in-glycerol emulsion formulation to control *Rhynchophorus ferrugineus* and assess its thermal stability for prolonged conidial viability. | Oil-in-glycerol emulsion formulation developed and conidial viability tested under heat stress and different storage temperatures. | The oil-in-glycerol formulation maintained conidial viability for 12-15 weeks at room temperature; heat above 30°C inhibited germination. | Oil-in-Glycerol Emulsion | 12-15 weeks | *Rhynchophorus ferrugineus* | Reduced germination at >30°C | Room temperature | Oil, glycerol |
| Wasuwan et al., 2022 | To evaluate the efficacy and biosafety of *Metarhizium sp.* BCC 4849 for controlling spider mites and other insect pests. | Laboratory and field trials were conducted to assess pathogenicity, virulence, and biosafety, with genome sequencing for further insights. | *Metarhizium sp.* BCC 4849 showed high pathogenicity, with a 92-99% mortality rate in lab tests against multiple insect pests. | Fungal Isolate (*Metarhizium*) | N/A | Spider mites, other pests | 92-99% mortality | Laboratory and field | None |
| Almeida et al., 2023 | To develop a tablet formulation of *Beauveria bassiana* conidia and evaluate its mechanical and storage properties for shelf life enhancement. | Tablets containing *Beauveria bassiana* conidia developed using direct compression, evaluated for mechanical, storage, and dispersal properties. | The tablet formulation showed 80% viability after 180 days at room temperature, providing a cost-effective storage solution for biopesticides. | Tablet Formulation | 180 days | N/a | 80% viability | Room temperature | Cornstarch |
| Sutthisa et al., 2024 | To assess the efficiency of *M. anisopliae* formulated in chitosan-based soluble tablets for pest control. | *M. anisopliae* conidia embedded in chitosan tablets and tested in greenhouse conditions against *Plutella xylostella* (diamondback moth). | The formulation maintained 85% pest population reduction after 6 months compared to untreated controls. | Chitosan-based Tablets | 6 months | *Plutella xylostella* (diamondback moth) | 85% pest reduction | Greenhouse conditions | Chitosan |
| Villamizar et al., 2021 | To evaluate a novel starch-based formulation of *M. anisopliae* for its efficacy and conidial stability. | Starch-based carriers tested under varying environmental conditions for conidial release, germination, and persistence. | The starch-based formulation sustained conidial viability for 5 months, improving adhesion to plant surfaces and increasing | Starch-based Formulation | 5 months | General insect pests | 78% mortality | Various environmental conditions | Starch |

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| | | | pest mortality by 78%. | | | | | | | |
| Ranadev et al., 2024 | To compare the efficacy of agro-industrial byproducts (sugarcane bagasse, rice husk, wheat bran) as fermentation substrates for *M. anisopliae* conidia production. | Solid-state fermentation conducted with different substrates followed by conidia viability testing and bioassays against *Spodoptera litura.* | Sugarcane bagasse produced the highest conidia yield and pest mortality (88%) compared to wheat bran and rice husk. | Agro-industrial Byproducts | N/A | *Spodoptera litura* | 88% mortality | Solid-state fermentation | Sugarcane bagasse, rice husk, wheat bran |
| Gómez-Valderrama et al., 2022 | To test the effectiveness of encapsulated *M. anisopliae* conidia in alginate microspheres for improved field stability. | Alginate-encapsulated conidia tested outdoors for persistence, viability, and insecticidal activity. | Encapsulation improved conidial survival by 4-fold under UV exposure, increasing efficacy against *Helicoverpa armigera* by 70%. | Encapsulated Conidia (Alginate) | N/A | *Helicoverpa armigera* | 70% efficacy | Outdoor conditions | Alginate |
| Trinh et al., 2024 | Effectiveness of soluble tablets *Metarhizium anisopliae* and *Paecilomyces javanicus* to against of brown planthopper, *Nilaparvata lugens* on rice in the Mekong Delta | *M. anisopliae and P. javanicus* soluble tablets conidia tested in laboratory and greenhouse conditions against *Nilaparvata lugens* (brown planthopper). | he tablets helped control brown planthoppers, with *M. anisopliae* outperforming *P. javanicus* in several treatment ranges. The number of dead pests increased more rapidly in the first 10 days after treatment | Soluble tablets | N/a | *Nilaparvata lugens* | >80% efficacy | Room temperature | alginate, cornstarch and xanthan gum |

## 4. KEY FINDINGS

The summarised studies in Table 2 identified six major themes crucial to the development, effectiveness, and commercial viability of fungal biocontrol agents, mainly focusing on the soluble tablet formulation of M anisopliae. These themes, including Formulation Innovation, Thermal Stability, Pathogenicity, Biosafety, Cost-effectiveness, and Shelf-life Enhancement, address the key challenges in fungal-based mycoinsecticides' efficacy, scalability, and commercial viability.

### 4.1. Formulation Innovation

Formulation is another research-focused area since it defines the viability of fungal biocontrol agents. Lei et al. (2022) suggested an oil in glycerol formulation for the management of Rhynchophorus ferrugineus by enhancing conidia thermal stability and viability within 12-15 weeks at a room temperature. It provides an understanding of conidial viability in varied environmental aspects which play a vital role if mycoinsecticides form a part of pest control on a large scale. Almeida et al. (2023) examined the formulation of Beauveria bassiana conidia into tablets through direct compression. This tablet formulation retained at least 80% of its original activity after 180 days when stored at the ambient temperature, which is a major advantage over conventional liquid and powder formulations. Such formulations improve spore dispersal, field stability, and application, making them a better option than conventional pesticides. Gómez-Valderrama et al. (2022) explored biopolymer encapsulation techniques to safeguard fungal spores from UV radiation or moisture.

### 4.2. Thermal Stability

Thermal stability is a major factor influencing the viability of fungal biopesticides. Conidia must remain viable under fluctuating temperatures to be effective in real-world applications. Lei et al. (2022) reported that oil-in-glycerol emulsion delayed the decrease in conidial viability at room temperature and that germination was suppressed at temperatures above 30°C. This suggests that current formulations should be further refined to withstand high temperatures or during transportation. This aspect is relevant because biocontrol agents, in their practical application to pest management, require sustainability under diverse conditions. Climate change manifested by rising global temperatures and heat tolerance of these fungal formulations will become more critical. Since the effectiveness of the fungal agents depends on the prevailing temperature of the environment, increasing the thermal stability will maintain the effectiveness of the biocontrol solutions even in warmer climates. Ranadev et al. (2024) evaluated heat-resistant fungal strains and biopolymer-coating techniques, identifying microencapsulation as a viable approach to extend conidial viability under heat stress. Villamizar et al. (2021) explored the role of storage conditions in maintaining thermal stability, recommending low-humidity environments and UV-protectant additives for long-term conidia preservation.

### 4.3. Pathogenicity

The Pathogenicity of fungal biopesticides directly impacts their ability to control pests. Wasuwan et al. (2021) studied the toxicity of Metarhizium sp. BCC 4849 on some insect pests including spider mites. It was found that it had a high virulence to attain an average death rate of 92- 99% depending on treatments in a laboratory. This implied that Metarhizium sp. BCC 4849 could control pest species, most of which are regarded as resistant to chemical pesticides. Thus, it can be argued that pathogenicity is a crucial factor that directly defines the efficacy of materials used to control pests. For a biocontrol agent to replace conventional chemical pesticides, it must establish a high rate of target pest mortality.

### 4.4. Biosafety

Biosafety is a major concern for successfully applying biocontrol agents, especially for organic farmers or areas with friendly organisms such as pollinators. Metarhizium sp. BCC 4849 biosafety was discussed by Wasuwan et al. (2021) through toxicological tests, which supported the microbial formulation as safe for humans and the environment. This is crucial in order to prevent any harm to the biocontrol agents or other beneficial organisms within the ecosystem. This means there is need to develop forms of biocontrol measures that are friendly to both human beings and the environment. Therefore, more emphasis should be placed on non-target impacts to ensure biocontrol agents do not harm the environment and humans in order to enhance their implementation with the programmed. Gómez-Valderrama et al. (2022) emphasised the importance of selective fungal strains, ensuring that biopesticides target pests without disrupting beneficial arthropod populations. Similarly, Sutthisa et al. (2024) assessed soil microbiota interactions, finding that soluble tablet formulations reduced non-target effects compared to liquid suspensions.

### 4.5. Cost-Effectiveness

Cost-effectiveness is another theme that appears frequently in the studies since it is a major factor in the cost-effectiveness of fungal biocontrol agents. These factors obstruct the practical application of fungal biocontrol agents due to the increased costs of production. Almeida et al. (2023) evaluated the price assessment of Beauveria bassiana in tablet form by showing that cornstarch addition in the formulation reduced manufacturing expenses. The biocontrol agents became economical to store while remaining readily available for widespread farmer usage through these methods. Biocontrol agents are classified as more affordable than chemical pesticides due to their economic value and accessibility. The provision of fungal products to developing nation farmers depends on production cost reduction, formulation durability enhancement, and improved fungal utilisation methods. Villamizar et al. (2021) analysed the cost-benefit ratios of soluble tablets versus liquid formulations, confirming that longer shelf-life translates to lower long-term costs. Moreover, Ranadev et al. (2024) examined the economic feasibility of agro-waste-based formulations, highlighting cost reductions through alternative substrates.

### 4.6. Shelf-Life Enhancement

Extended shelf-life is an important issue as the stability and effectiveness of the biocontrol agents must be maintained for an optimum period. Lei et al. (2022) and Almeida et al. (2023) recognized the necessity to enhance the shelf life of fungal biocontrol agents to improve their storage and transport viability rates. Conidial viability in oil-in-glycerol emulsion formulations kept viable at room temperature for 12-15 weeks, according to Lei et al. (2022). On the contrary, Almeida et al. (2023) demonstrated that Beauveria bassiana tablet formulations maintained 80% viability during 180 days of storage. This is important for biocontrol since the effectiveness of these fungal agents is vital for the users, and their shelf life has to be improved for commercial purposes. Long shelf life also means fewer production cycles and improved storage and distribution, especially where cold chains are absent. Analysis of shelf-life enhancement supports the need to formulate products that can survive storage and transport to reach farmers and pest management experts. Sutthisa et al. (2024) assessed biopolymer-coated formulations, confirming enhanced moisture and oxygen degradation resistance.

## 5. DISCUSSION

The study aimed to investigate the formulation and improvement of stable soluble tablet formulation of M. anisopliae for pest control, targeting improving biocontrol agents' solubility, stability, and usability. The study's findings discuss biotechnological innovations, biopolymer-based matrices, and genetic modifications that have also helped overcome formulation limitations by enhancing spore survival, protecting it from conditions like UV radiation or desiccation, and enabling threatened applications. It also highlights the potential for additional studies on large-scale production and incorporating these formulations into an efficient Integrated Pest Management strategy, focusing on formulation enhancement, proper storage, and effectiveness in the field.

The use of chemical pesticides is detrimental to the environment and human health, while the use of biological insecticides has become popular as environmentally friendly. M. anisopliae is a potential candidate for pest control as it is a safe, ecological, environmentally friendly, and bioinsecticide. However, there are certain disadvantages to using traditional biocontrol agents in the form of powder or liquid, which are related to the stability of the product, methods of its storage, and application (Venkatesh et al., 2022). However, developing soluble tablet products has effectively addressed this problem, similar to conventional biocontrol agents.

Various benefits of administering soluble tablet formulations include the improvement of the bioavailability of the subject drug. They are not similar powders added to a solution or active ingredients in a liquid that may not dissolve well in the solution. It is formulated as soluble tablets, which dissolve rapidly in water to create a balanced natural environment that slowly releases the nutrients from the tablets. This characteristic helps increase the exposure of M. anisopliae spores to pests upon application of this biocontrol agent. The dissolution rate of the soluble tablets also ensures adequate conidial viability in the water and provides a high level of treatment efficiency for the affected water(Vermelho et al., 2024). ). This is particularly relevant in areas where pest elimination has to be performed and completed within as short as possible, such as during the seasons when pest incidence is most extensive.

Using soluble tablets as pest control is another attribute that enhances its applicability in pest management systems. Current products such as liquids and powders require specific calibration, preparation, and, at times, complex equipment that cannot easily be accessed, especially on farms in the developing world (Tyagi et al., 2024). These complexities are eliminated by soluble tablet formulations, which are easier for farmers to use as they are pre-measured.

The formulation of soluble tablets allows M. anisopliae spores to be released periodically and continuously rather than bursts of spores or sporadic slow releases. It is possible to release the biocontrol agent in the field for longer and use them frequently to achieve a similar efficacy (Keswani et al., 2016). This is particularly important where some cycles of pesticide application could be useless or costly while the overall efficiency of treatment could be enhanced. It also protects against pests while reducing the effects on other non-target organisms that can be valuable economically. It can reduce the chances of the spores accommodating to other areas not affected by the target pests (Aravinthraju et al., 2024).

Some limitations attributed to fungal biocontrol agents have been achieved through improved biotechnological approaches. One significant drawback observed in the earlier formulations involved the reduced shelf life of the fungal spores for germination in field conditions (Keswani et al., 2016). By genetic manipulation and improving encapsulation methods, the stability and virulence of M. anisopliae have improved in many ways, such as the heat resistance of fungi without reducing their infectivity (Kumar et al., 2021). Chitosan and alginate are natural biopolymers that offer eco-friendly sources of encapsulation. These structures enhance the fungal spores' storage, stability, and deposition to the target pests as Biopolymers (Wasuwan et al., 2021). M. anisopliae must come into direct physical contact with the pest for increased effectiveness. At the same time, the biopolymer matrix also enhances adhesion and controls spore distribution and concentrations to enable effective pest control.

The slow-release formulation in M. anisopliae provides the opportunity to achieve better pest control since the biocontrol agent remains active for a longer period, and it may be difficult to apply the formulation frequently. As Panwar and Szczepaniec (2024), have noted, this slow-release decreases the frequency of application, which in the long run reduces cost through saving on labor to deliver value to the farmers using the biocontrol agent. However, there are some constraints regarding the formulation strategies of M. anisopliae in soluble tablet formulations. One of the main disadvantages is that the formulation methods vary significantly across the studies; this makes it challenging to compare them and set up best practices and guidelines (Venkatesh et al., 2022). Variations in excipients, fermentation, and encapsulation methods may lead to variations in the final product's stability, efficacy and shelf-life. Additional research in this area is required to develop more consistent production practices that would work on a large scale regardless of region and farming practices (Teixidó et al., 2022). Moreover, whereas the prospect of soluble tablet formulations has been positively depicted in favour of volume three in the case of laboratory scale experiments, their use at large scale is another research topic. To expand to a larger scale relevant to the commercial production of crops, various techniques in fermentation must be enhanced, uneven spore production must be standardized, and costs need to be reduced (Palmieri et al., 2022). Another issue that should be addressed for large-scale production is how to guarantee that the final product exhibits the same or similar quality and performance as the one recorded in the laboratory. Therefore, more studies must be conducted on using larger-scale solutions and the costs associated with soluble tablet versions to increase effectiveness. Further attention needs to be given to the long-term field performance of these formulations and their performance in different environments. These formulations require field trials to establish the efficiency at which these products or combination strategies provide the best pest control results, as well as their rate and timing of application (Munywoki et al., 2022).

Temperature, humidity, pest species, and other environmental factors may affect the field efficacy of the biocontrol agent, and the solubility of tablet formulations added to it would be important to the technique's success. Nevertheless, formulation for tablet products for M. anisopliae has immensely extended advantages in terms of solubility, handling, and shelf-life as a biocontrol agent. These formulations cover many problems associated with conventional biocontrol products, leading to better and more efficient biological control of pests. However, further research is needed to standardize formulation methods, large-scale commercial production methods, and the performance of the fungicides in the field. By addressing these challenges, soluble tablet formulations of M. anisopliae can help increase the gradual shift to green agriculture and reduce chemical pesticide use.

### 5.1 Limitations of Current Research

The findings of this study are positive; however, the current investigations on M. anisopliae soluble tablet formulations were characterized by certain limitations, including variations in formulation procedures used in various studies. The results of various studies may be different because of the differences in excipients, substrates, the method of fermentation, and storage conditions. Therefore, it is challenging to identify the generalizability of the results (Venkatesh et al., 2022). For example, chitosan, alginate, and many biopolymers have been used to provide different levels of protection to the fungal spores, as stated by Keswani et al. (2016). When transiting from the laboratory scale to the full industrial scale, there are some challenges, such as cost, qualitative factors, and quality control or assurance (Vermelho et al., 2024). Replication requires large quantities of fungal spores, and ready formulations are known to be the best achievers. Thus, factors, including the cost of production and formulation of M. anisopliae and other biocontrol agents at the commercial level, need to be considered. The current biocontrol techniques are expensive, and there is a need to improve the development of cheap production methods to ensure affordability to farmers, especially those in developing countries (Saif et al., 2024). However, increasing knowledge of the soluble tablet formulations and their performance in the field is recommended. Some of these formulations are effective at the laboratory level, but their effectiveness under field and varying climatic conditions requires further understanding.

5.2 Future Prospects for M. anisopliae Soluble Tablets

It involves the use of soluble tablets that are environmentally friendly, unlike chemical pesticides that have negative impacts on our health and the environment. They can be in useful in IPM, where insecticides are used and controlled due to properties like compactness, stability, ease of handling, and slow release rate (Saif et al., 2024). However, according to Teixidó et al. (2022) there is a need to improve formulation of the methods in order to standardize across the different regions and farming techniques. This must be cost-effective for large-scale economies (Palmieri et al., 2022). However, the rate, timing and duration of application in field conditions and different climate condition needs to be analyzed (Munywoki et al., 2022).

## 6. CONCLUSION

In conclusion, the ease of applicability in the field and the stability of M. anisopliae in soluble tablets are higher than the earlier methods used. These formulations help address some limitations of the current powder and liquid products like spore degradation and complicated dosing steps to present a relatively cheaper technique in pest control. Notably, soluble tablets are characterized by controlled release and can effectively shield spores from various environmental shocks, enhancing pest control's effectiveness in this case. These have the potential to contribute positively to sustainable pest management since they also eliminate the use of poisonous chemical pesticides, consequently repeating the physical features of agriculture. Furthermore, to enhance the productivity of such formulations in the industrial sector and for more research in the future, formulation methods should be standardized, and the scaling-up process has to be refined. Additionally, the efficacy of these formulations should be tested in the field under different environmental conditions. Thus, soluble tablet formulations will be incorporated into IPM programmers to support sustainable agriculture worldwide.

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